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Assessment of vertical facial and dentoalveolar changes using panoramic radiography

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SUMMARY The purpose of the study was to analyse longitudinal vertical facial and dentoalveolar changes using panoramic radiographs (PRs) and to compare the results with measurements on lateral cephalometric radiographs (LCRs) in order to determine whether, under certain circumstances, the radiation dose for a patient may be reduced by taking only a PR instead of a PR and a LCR. Pre- and post-treatment PRs and LCRs of 30 (15 females and 15 males) orthodontically treated adolescents (mean age pre-treatment 10.9 years, post-treatment 13.4 years) were analysed using Pearson's correlation coefficients and gender differences using Fisher's *z*-transformation.

The results revealed that most variables exhibited larger absolute values on PRs than on LCRs. Comparison of dentoskeletal morphology between the LCRs and the PRs revealed moderate to high, mostly statistically significant, interrelations both before and after orthodontic treatment. The lowest correlations were found for the maxillary jaw base angle (NL/H; $r = 0.35$***) and the highest for the gonial angle (ML/RL; $r = 0.90$***). However, when assessing the combined growth and treatment changes from before to after treatment, only weak to moderate, not statistically significant, interrelations were found between LCRs and PRs. Anterior face height (AFH; $r = 0.43$***), the mandibular plane angle (ML/H; $r = 0.06$*), and the distance of the incisal tip of the most extruded mandibular incisor to the ML-line (ii-ML; $r = -0.21$*) were the only statistically significant parameters. The average group differences for growth and treatment changes, however, were small for most parameters.

Analysis of vertical facial and dentoalveolar parameters on PRs delivers a moderate approximation to the situation depicted on LCRs. However, PRs cannot be recommended for the analysis of individual longitudinal changes in vertical facial and dentoalveolar parameters.

Introduction

Although radiation doses during dental examinations are in general relatively low, they account for nearly one-third of the total number of radiological examinations in the European Union (EU; Janssens *et al.*, 2004). Despite the fact that according to the official guidelines adopted by the EU (Isaacson and Thom, 2001) lateral cephalometric radiographs (LCRs) should be restricted to severe malocclusions, an average of three panoramic radiographs (PRs) and three LCRs are taken of orthodontic patients (Hujoel *et al.*, 2006). A reduction in the number of radiographs during orthodontic treatment is supported by the findings that a clinical examination supplemented by study models is often sufficient for treatment planning (Han *et al.*, 1991) and that a treatment plan based on clinical examination, study models, and photographs is only altered in 7 per cent of the cases due to an additional radiographic examination (Bruks *et al.*, 1999).

If the EU guidelines are followed and no LCRs are taken of patients with mild to moderate malocclusion, certain information normally derived from LCRs, such as the vertical jaw base relationship and gonial angles, are missing. These parameters are among others used to predict the mandibular growth pattern (Björk, 1969). It would thus be useful if this information could be derived from PRs.

PRs have been used previously to metrically assess gonial angles, condylar and ramus heights, as well as asymmetries (Mattila *et al.*, 1977; Kjellberg *et al.*, 1994; Raustia and Salonen, 1997; Dutra *et al.*, 2004) and showed high correlations for gonial angles, interjaw base angle, and anterior and posterior face height (Dahan and Jesdinsky, 1968; Mattila *et al.*, 1977; Raustia and Salonen, 1997). However, all corresponding studies available in the literature have been cross-sectional.

Although there are longitudinal studies that have used PRs to assess long-term changes of bone growth after implant placement (Roberts, 2005) or longitudinal morphological changes of the mandible in patients with hemifacial microsomia (Sarnas *et al.*, 2004), it is not clear whether such longitudinal changes assessed using PRs represent the true changes.

Thus, the aim of the study was to analyse longitudinal vertical facial parameters and dentoalveolar bone height using PRs and to compare the results to measurements on LCRs in order to determine whether the radiation dose for the patient may be reduced by taking only a PR instead of a PR and a LCR in certain indications.

Subjects and methods

The study comprised 30 orthodontically treated adolescent subjects (15 females and 15 males). The average pre-treatment age of the patients was 10.9 years and post-treatment 13.4 years.

From all patients completing active orthodontic treatment in the Department of Orthodontics of the University of Giessen in 1999, the first 30 subjects fulfilling the following inclusion criteria were selected: fully erupted first molars and permanent incisors at the time of the initial investigation, no disabilities, syndromes, severe asymmetries, or multiple tooth agenesis, as well as available good-quality LCRs and PRs from before and after treatment taken exclusively by one operator.

The LCRs and PRs had been taken as part of the routine diagnostic procedures for orthodontic treatment and were retrospectively analysed. Both radiographs (LCR and PR) of each subject were required to be taken on the same day before and after treatment, respectively. The average time interval between the before (T1) and after treatment (T2) radiographs was 2.5 years. All radiographs were taken with the same X-ray machine (Orthophos CD, Siemens, Munich Germany) at both examination times.

The LCRs and PRs from both examination times were taken in ideal position according to the manufacturers' operating instructions. The radiographs were traced and analysed using a modified 'cephalometric' analysis based on comparable reference points, which could be located on both the LCR and the PR (Tables 1 and 2 and Figures 1–5).

Double contours on the LCR were averaged, while on the PR the reference points were located separately for the left and right side. Measurements were performed to the nearest 0.5 mm or 0.5 degrees, respectively.

All registrations were performed twice by one investigator (MAB, see acknowledgements), and the mean value of the duplicate registrations was used in the final evaluation. Before the evaluation, the investigator was calibrated to identify the anatomical points on the PRs. For all variables, the arithmetic mean (mean) and standard deviation (SD) were calculated. No correction for linear enlargement was performed. Possible interrelations between the variables and the treatment changes measured on the LCRs and PRs were assessed by means of Pearson's correlation coefficients. Gender differences were analysed using Fisher's z-transformation. The following correlation categories were established: weak ($r < 0.30$), moderate ($r = 0.30–0.70$), and strong ($r > 0.70$). Statistical significance was determined at the 0.1, 1, and 5 per cent levels of confidence. A confidence level larger than 5 per cent was considered not significant.

Repeated measurements were used for the method error (ME) calculation: $\mathrm{ME} = \sqrt{(\sum d^2/2n)}$, where d is the difference between two registrations of a pair and n is the number of double registrations. The combined ME in locating, superimposing, and measuring the changes of the different landmarks did not exceed 1.0 mm or 1.5 degrees, respectively, for any of the variables investigated. The ME did not differ between LCRs and PRs.

Table 1 Definition of the reference points and reference lines used in the analysis of the lateral cephalometric radiographs (LCRs) and panoramic radiographs (PRs).

Variable	Definition
Co	Condylion: most superior point of the condyle
Cod	Condylion dorsale: most posterior point of the condyle
Or	Orbitale: most inferior point of the orbital wall
Sp (LCR)	Spina nasalis anterior: tip of the anterior nasal spine
Sp (PR)	Spina nasalis anterior: most inferior point in which the nasal borders of the maxillary bones meet in the median sagittal plane
Pm	Pterygomaxillare: intersection of the nasal line (NL) and the pterygomaxillary fissure
Tgc	Corpus tangent point: contact point in the gonial area of the tangent to the lower mandibular border, which runs through point Gn
Gn (LCR)	Gnathion: most inferior point of the lower contour of the bony chin
Gn (PR)	Gnathion: most inferior point of the mandible in the canine region of each side
m (PR)	Gnathion mediana: most inferior point of the contour of the bony chin in the median plane
Go´	Gonial tangent point: intersection of a tangent to the posterior border of the ramus through Cod and a tangent through Tgc and Gn
is	Incision superior: incisal tip of the most prominent maxillary central incisor
is-a	Apex incision superior: root apex of the most prominent maxillary central incisor
ii	Incision inferior: incisal tip of the most prominent mandibular central incisor
ii-a	Apex incision inferior: root apex of the most prominent mandibular central incisor
ms	Molar superior: mesial cusp tip of the first upper molar
ms-a	Apex molaris superioris: mesial root apex of the first upper molar
mi	Molar inferior: mesial cusp tip of the first lower molar
mi-a	Apex molaris inferioris: mesial root apex of the first lower molar
al-is	Limbus alveolaris incision superior: highest point of the alveolar ridge in the upper incisor area
al-ii	Limbus alveolaris incision inferior: highest point of the alveolar ridge in the lower incisor area
al-ms	Limbus alveolaris molar superior: highest point of the alveolar ridge between the first and the second upper molars
al-mi	Limbus alveolaris molar superior: highest point of the alveolar ridge between the first and the second lower molars
Hv (PR)	Intersection between the H-line and the RL-line
Ht (PR)	Intersection between the H-lines of the right and left side
H	H-line: modified Frankfort horizontal. Line through Or and Co
NL	Nasal line: line through Sp and Pm
ML	Mandibular line: line through Gn and Tgc
MLa (PR)	Anterior mandibular line: line through Gn of each side
RL	Ramus tangent: tangent to the posterior border of the ramus through Cod

Table 2 Definition of the skeletal (1–6), alveolar (7–10), and dental (11–18) variables used in the analysis of the lateral cephalometric radiographs (LCRs) and panoramic radiographs (PRs).

	Variable	Definition
1	AFH (mm)	Anterior face height (LCR): vertical distance between Gn and the H-line
	AFH (mm)	Anterior face height (PR): distance between Ht and m
2	PFH (mm)	Posterior face height (LCR): vertical distance between Gò and the H-line
	PFH (mm)	Posterior face height (PR): distance between Hv and Gò
3	ML/RL (degree)	Gonial angle: angle between the reference lines ML and RL
4	ML/H (degree)	Mandibular plane angle: angle between the reference lines ML and H
5	NL/H (degree)	Maxillary plane angle: angle between the reference lines NL and H
6	ML/NL (degree)	Interjaw-base angle: angle between the reference lines ML and NL
7	AHMx (mm)	Anterior maxillary height (LCR): vertical distance between al-is and NL
	AHMx (mm)	Anterior maxillary height (PR): distance between al-is and Sp
8	PHMx (mm)	Posterior maxillary height: vertical distance between al-ms and NL
9	AHMn (mm)	Anterior mandibular height (LCR): vertical distance between al-ii and ML
	AHMn (mm)	Anterior mandibular height (PR): distance between al-ii and m
10	PHMn (mm)	Posterior mandibular height: vertical distance between al-mi and ML
11	is-NL (mm)	Distance of the incisal tip of the most extruded maxillary incisor to NL
12	ii-ML (mm)	LCR: distance of the incisal tip of the most extruded mandibular central incisor to ML
	ii-MLa (mm)	PR: distance of the incisal tip of the most extruded mandibular central incisor to MLa
13	ms-NL (mm)	Distance of the mesial cusp tip of the first permanent upper molar to NL
14	mi-ML (mm)	Distance of the mesial cusp tip of the first permanent lower molar to ML
15	isa-NL (mm)	Distance of the root apex of the most extruded maxillary central incisor to NL
16	iia-ML (mm)	LCR: distance of the root apex of the most extruded mandibular central incisor to ML
	iia-MLa (mm)	PR: distance of the root apex of the most extruded mandibular central incisor to MLa
17	msa-NL	Distance of the root apex of the mesial root of the first permanent upper molar to NL
18	mia-ML	Distance of the root apex of the mesial root of the first permanent lower molar to ML

Results

Dentoskeletal morphology

The results of the analysis and comparison of the dentoskeletal morphology before and after treatment, are shown in Table 3. Except for gonial angle (ML/RL), interjaw-base angle (ML/NL), anterior maxillary height (AHMx), and the distance between the root apex of the most extruded upper incisor to the NL-line (isa-NL), all PR variables exhibited larger absolute values.

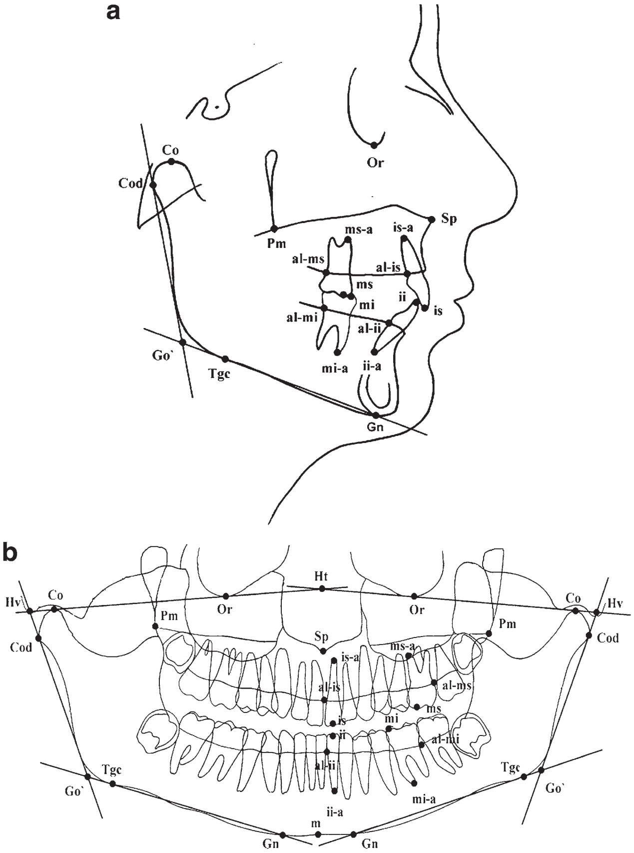

Figure 1 Reference points used in the analysis of (a) the lateral cephalometric and (b) the panoramic radiographs.

Comparison of dentoskeletal measurements on LCRs and PRs revealed moderate to high, mostly statistically significant interrelationships. The lowest correlations were found for the maxillary jaw base angle (NL/H; $r = 0.35$***) and the highest for the gonial angle (ML/RL; $r = 0.90$***). No systematic gender differences were found for any of the interrelationships analysed.

Growth and treatment changes

The results of the analysis and comparison of the growth and treatment changes occurring from before to after treatment are given in Table 4. Most parameters exhibited only small average differences [mean(d) = 0.0–0.8 mm and 0.1–0.2 degrees, respectively] between the growth and the treatment changes measured on LCRs and PRs. The SDs, however, were large. The variables, anterior face height (AFH), mandibular plane angle (ML/H), interjaw-base angle (ML/NL), and the distance of the incisal tip of the most extruded mandibular incisor to the ML-line (ii-ML), on the other hand, exhibited larger mean differences [mean(d) = 1.9–4.2 mm and 1.7–1.9 degrees, respectively] with all growth and treatment changes being smaller on the PRs.

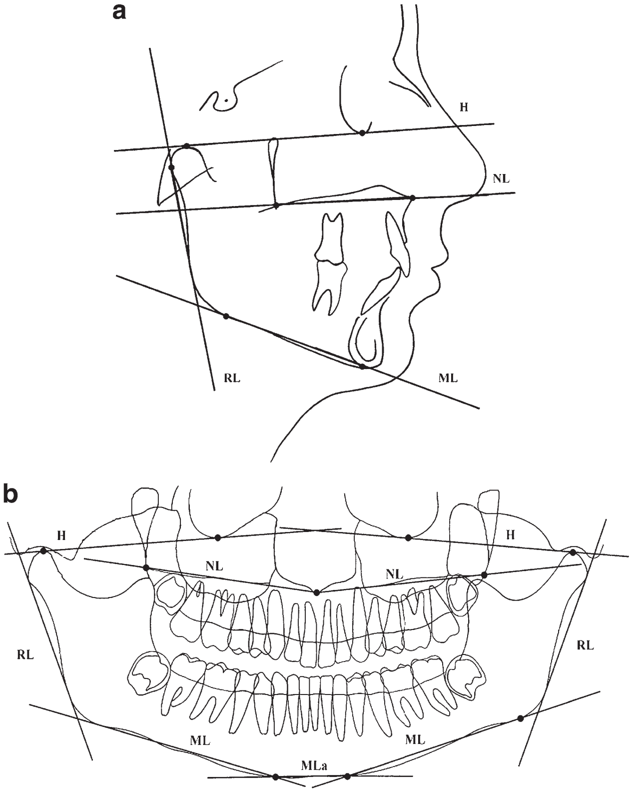

Figure 2 Reference lines used in the analysis of (a) the lateral cephalometric and (b) the panoramic radiographs.

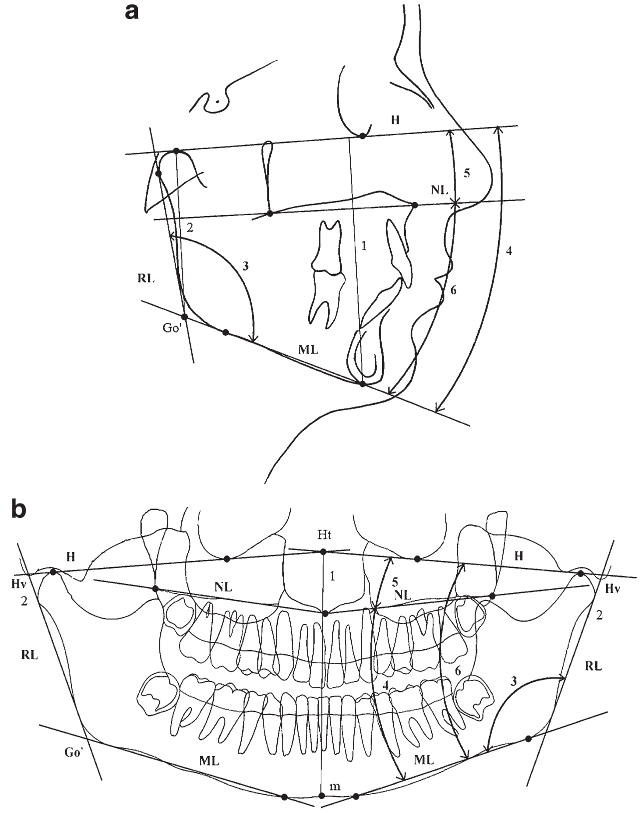

Figure 3 Skeletal variables, AFH (1), PFH (2), ML/RL (3), ML/H (4), NL/H (5), and ML/NL (6) used in the analysis of (a) the lateral cephalometric and (b) the panoramic radiographs.

In contrast to the dentoskeletal measurements, the growth and treatment changes on the LCRs and PRs showed only weak to moderate, mostly not statistically significant, interrelations. Anterior face height (AFH; $r = 0.43$***), the mandibular plane angle (ML/H; $r = 0.06$*), and the distance of the incisal tip of the most extruded mandibular incisor to the ML-line (ii-ML; $r = -0.21$*) were the only statistically significant parameters.

Discussion

To reduce the influence of measurement errors, one calibrated examiner evaluated all radiographs twice and the mean of the duplicate measurements was used in the final evaluation. No adjustment for radiographic enlargement was performed in the present study because the magnification of PRs will vary between 13 and 28 per cent depending on the area imaged and the panoramic machine used (Philipp and Hurst, 1978; McDavid *et al.*, 1985; Thanyakarn *et al.*, 1992). Furthermore, vertical measurements on PRs are more susceptible to projective distortion than vertical measurements on LCRs. While minor antero–posterior shifts and tilts affect vertical measurements only to a limited degree (Xie *et al.*, 1996), rotations, and, especially lateral tilts, result in left–right asymmetries (Ruf and Pancherz, 1995; Malkoc *et al.*, 2005).

It might be argued that LCRs are not a gold standard and instead a dry skull should have been used (Dermaut, 2002). However, longitudinal changes cannot be measured on dry skulls.

As expected, due to the larger magnification of the PRs (13–28 per cent; Philipp and Hurst, 1978; McDavid *et al.*, 1985; Thanyakarn *et al.*, 1992) compared with LCRs (10 per cent = average magnification value of the LCR unit), the majority of the PR parameters exhibited larger absolute values. The skeletal parameters showed larger differences between PRs and LCRs than the alveolar and dental parameters. Furthermore, two skeletal parameters (ML/RL and ML/NL) presented smaller values on the PRs. As both ML/RL and ML/NL are angular measurements, varying magnification cannot explain the differences. The largest vertical and horizontal distortions on the PRs were located at the border of the film and thus in the area of the mandibular ramus and the condyles. This distortion is larger in the upper compared with the lower part of the film (Samawi and Burke, 1984). This could explain why, in the present study, skeletal parameters showed more variability than alveolar and dental parameters.

In agreement with the literature (Dahan and Jesdinsky, 1968; Mattila *et al.*, 1977; Raustia and Salonen, 1997),

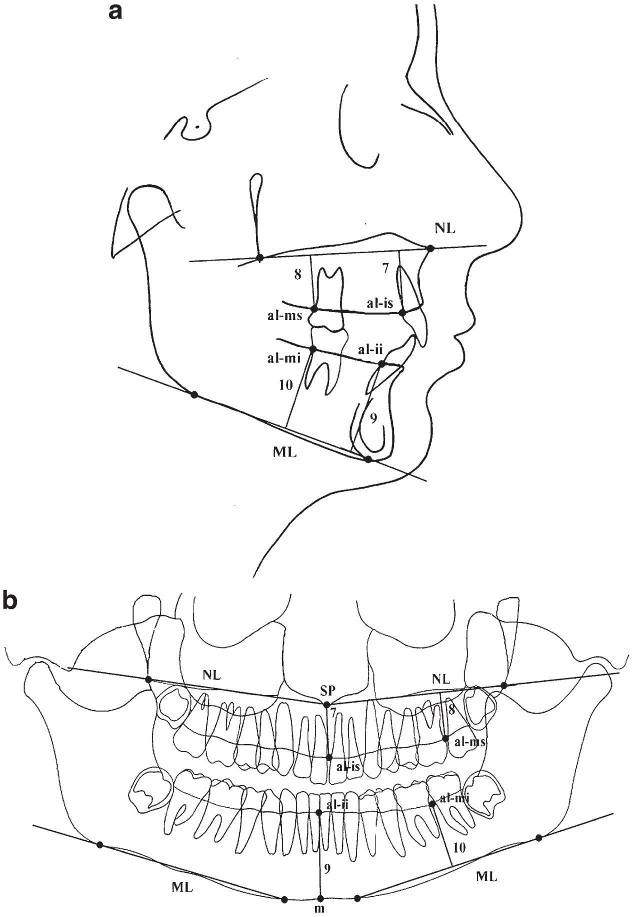

Figure 4 Alveolar variables, AHMx (7), PHMx (8), AHMn (9), and PHMn (10) used in the analysis of (a) the lateral cephalometric and (b) the panoramic radiographs.

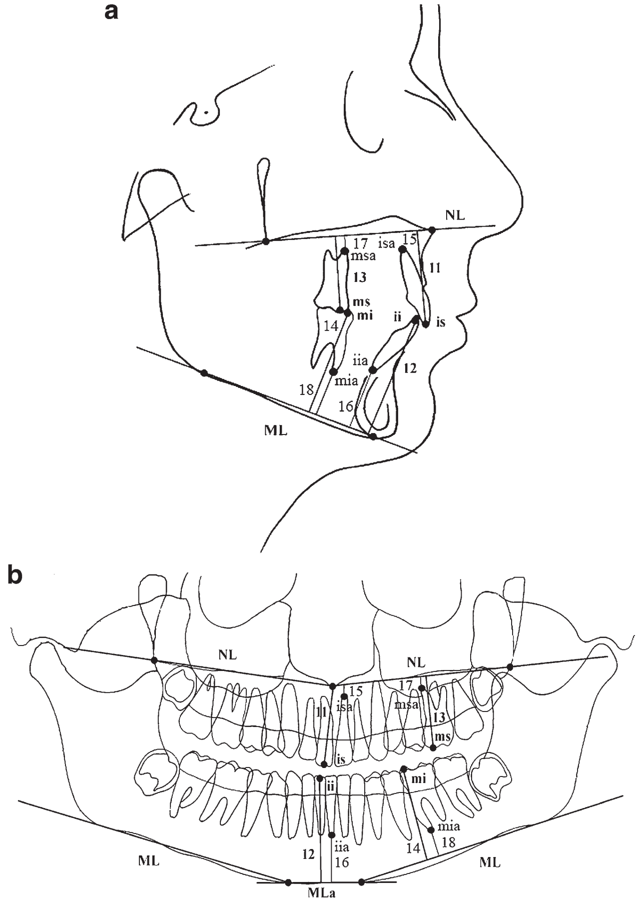

Figure 5 Dental variables, is-NL (11), ii-ML (12), ms-NL (13), mi-ML (14), isa-NL (15), iia-ML (16), msa-NL (17), and mia-ML used in the analysis of (a) the lateral cephalometric and (b) the panoramic radiographs.

comparison of the PR and LCR measurements on radiographs from the same day revealed moderate to high (r = 0.35–0.90) in most cases significant (P < 0.01, P < 0.001) interrelationships for the skeletal, alveolar, and dental parameters. The highest interrelationships (r = 0.90***) existed for gonial angle (ML/RL). No systematic gender difference was found for the interrelations. Therefore, male and female subjects were pooled in the analysis.

Analysis of the longitudinal facial and dentoalveolar changes and their comparison between LCRs and PRs showed only small mean differences, except for the parameters AFH, ML/H, and ii-ML. The SDs, however, were very large. The interindividual variation was obvious and the direction of changes inconsistent because the correlations for growth and treatment changes measured on PRs and LCRs were only weak to moderate and mostly not statistically significant.

The low correlations are most probably due to the varying degrees of distortion and enlargement within the PRs (Philipp and Hurst, 1978; Samawi and Burke, 1984; Thanyakarn *et al.*, 1992), the higher susceptibility for positioning errors (Philipp and Hurst, 1978; Samawi and Burke, 1984; Ruf and Pancherz, 1995; Xie *et al.*, 1996), as well as the difficulty in exactly reproducing a PR in case of repeated exposure (Larheim and Svanæs, 1986). Nevertheless, Stramotas *et al.* (2002) showed that comparing linear and angular measurements on PRs taken at different times is sufficiently accurate for measuring changes in root length and root parallelism, to assess sites for implant location, and to measure angulation of developing third molars, provided that the occlusal plane is kept at a similar angulation and is not tilted more than 10 degrees.

Another factor that influenced the differences found in the present study was the fact that the PRs and LCRs were obtained in different jaw positions (LCR = habitual occlusion; PR = incisor edge-to-edge). These different positions correspond to the standard imaging procedures (LCR) or standard manufacturers' instructions (PR). However, some measurements such as anterior face height, posterior face height, and mandibular plane angle can be

Table 3 Skeletal, alveolar, and dental variables measured on 60 lateral cephalometric radiographs (LCRs) and 60 panoramic radiographs (PRs) of 30 patients (15 females and 15 males). The mean values (mean), standard deviations (SD), mean value differences between LCR and PR [mean(d)], SDs of the difference [SD(d)], and the Pearson's correlation coefficients (r) are given.

Variable	LCR		PR		LCR − PR		Correlation
	Mean	SD	Mean	SD	Mean(d)	SD	r
Skeletal							
AFH (mm)	85.3	5.6	102.2	5.6	−16.9	5.1	0.59***
PFH (mm)	54.8	5.1	63.2	6.6	−8.4	3.8	0.82***
ML/RL (gradian)	126.8	6.0	124.7	6.2	+2.1	2.7	0.90***
ML/H (degree)	26.2	4.1	27.8	4.3	−1.6	3.5	0.65***
NL/H (degree)	2.1	1.6	9.6	2.8	−7.5	2.7	0.35***
ML/NL (degree)	24.7	4.6	18.0	4.9	+6.7	3.8	0.68***
Alveolar							
AHMx (mm)	18.3	1.6	18.2	2.6	+0.1	2.3	0.50 n.s.
PHMx (mm)	11.5	2.6	14.6	3.0	−3.1	1.9	0.78***
AHMn (mm)	30.2	3.0	34.6	2.8	−4.4	2.0	0.76***
PHMn (mm)	23.0	2.5	25.6	3.2	−2.6	2.0	0.77***
Dental							
is-NL (mm)	27.8	2.1	29.3	2.8	−1.5	1.8	0.76***
isa-NL (mm)	2.4	1.7	0.8	1.4	+1.6	1.5	0.56***
ii-ML (mm)	40.6	2.7	41.3	3.8	−0.7	3.5	0.48 n.s.
iia-ML (mm)	14.4	3.5	19.9	3.1	−5.5	2.3	0.75***
ms-NL (mm)	21.1	2.3	25.5	2.7	−4.4	2.0	0.70***
msa-NL (mm)	1.8	1.8	2.7	2.4	−0.9	1.8	0.69***
mi-ML (mm)	31.0	2.9	36.3	3.6	−5.3	1.8	0.87***
mia-ML (mm)	8.4	2.1	9.2	2.9	−0.8	1.9	0.76**

**$P < 0.01$, ***$P < 0.001$, n.s. = not significant.

Table 4 Growth and treatment changes of skeletal, alveolar, and dental variables measured on 60 lateral cephalometric radiographs (LCRs) and 60 panoramic radiographs (PRs) of 30 patients (15 females and 15 males). The mean value differences between LCR 2 − LCR 1, PR 2 − PR 1, LCR and PR [mean(d)], SDs of the difference [SD(d)], and the Pearson's correlation coefficients (r) are given.

Variable	Mean	Mean	LCR − PR		Correlation
	LCR 2 − LCR 1	PR 2 − PR 1	Mean(d)	SD	r
Skeletal					
AFH (mm)	5.1	0.9	+4.2	5.1	0.43***
PFH (mm)	3.6	3.5	+0.1	3.8	0.17 n.s.
ML/RL (gradian)	−0.8	−1.0	−0.7	2.7	0.33 n.s.
ML/H (degree)	0.1	−1.8	+1.9	3.5	0.06*
NL/H (degree)	0.1	0.0	+0.1	2.7	0.04 n.s.
ML/NL (degree)	0.2	−1.5	+1.7	3.8	0.35**
Alveolar					
AHMx (mm)	0.9	1.0	−0.1	2.3	0.16 n.s.
PHMx (mm)	2.3	2.8	−0.5	1.9	0.47 n.s.
AHMn (mm)	1.7	1.5	+0.2	2.0	0.44 n.s.
PHMn (mm)	0.7	0.6	+0.1	2.0	0.12 n.s.
Dental					
is-NL (mm)	0.9	1.0	−0.1	1.8	0.56 n.s.
isa-NL (mm)	0.2	0.5	−0.3	1.5	0.16 n.s.
ii-ML (mm)	1.7	−0.2	+1.9	3.5	−0.21*
iia-ML (mm)	1.7	1.8	−0.1	2.3	0.31 n.s.
ms-NL (mm)	2.0	2.0	0.0	2.0	0.29 n.s.
msa-NL (mm)	0.8	1.6	−0.8	1.8	0.21 n.s.
mi-ML (mm)	1.5	1.3	+0.2	1.8	0.49 n.s.
mia-ML (mm)	0.9	1.3	−0.4	1.9	0.41 n.s.

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, n.s. = not significant.

influenced due to the different mandibular position on the radiographs. No variation from these standard positions (e.g. taking the PRs in habitual occlusion) was attempted because this would have compromised the quality of the PR (overlapping of teeth, increased distortion, or blurring in the lower anterior segment). Furthermore, this would have counteracted the aim which was to assess whether a standard PR could deliver certain information normally derived from LCRs in order to be able to reduce the radiation dose for the patient by taking only a PR instead of a PR and a LCR.

The main positioning error when taking repeated LCRs is a change in the anterior or posterior inclination of the head. This does, however, not result in projection or distortion errors and, therefore, does not affect vertical measurements. In PR, on the other hand, a change in head inclination results in blurring, distortion, or enlargement of those areas, due to the fact that the head position change becomes located outside the imaging plane.

Conclusions

Analysis of vertical facial and dentoalveolar parameters on PRs delivers a moderate approximation of the situation depicted on LCRs. However, PRs cannot be recommended for analysis of individual longitudinal changes in vertical facial and dentoalveolar parameters.

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